# Silurian-Devonian sub-parallel ridge-trench interaction in Western Junggar and North-Central Tianshan in NW China: Alternative genesis of archipelagic architecture

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**ABSTRACT**

Western Junggar and North-Central Tianshan in NW China comprise a double magmatic belt, which evolved as a result of 446-380 Ma SSZ-type gabbro-basalt-andesite-diorite-granite-rhyolite magmatism that intruded a 504-446 Ma accretionary complex in SW Junggar and coeval magmatic arc in Central Tianshan. This orogenic framework is interpreted as a product of sub-parallel ridge-trench interaction, which generated the double magmatic belt together with adakitic intrusions in the older accretionary complex. In this model, a buoyant subducted ridge stalled and separated the double magmatic belts, resulting in the opening of a new 414-325 Ma intra-arc ocean, which is represented by Nb-depleted OIB- and MORB-type ophiolites. Mafic rocks generated by sea floor spreading in the modern Gulf of California record a similar evolution and chemistry. This new ocean split the northern accretionary complex along Mt. Xiemisitai-Barleik-Mayile line, leading to deposition of Devonian shallow marine-terrestrial sediments and cessation of magmatism at 380-349 Ma; this evolution also resembles that of the late Cenozoic passive margins of Baja California. Subsequent removal of the new ocean and its ridge-subduction gave rise to an archipelagic framework in the Late Paleozoic. A worldwide analysis of published examples of sub-parallel ridge-trench interaction indicates that a ridge jump can lead to multiple episodes of subduction, which could occur long before terminal ocean closure.

## INTRODUCTION

A spreading ridge can interact with a trench at a range of convergence angles (Sisson et al., 2003). Sub-parallel subduction can generate a short-lived magmatic belt in a forearc setting, adjacent to a magmatic arc, comparable to relations in Eocene Alaska, modern western California and the Chile triple junction (Sisson et al., 2003); we term these synchronous sub-parallel magmatic belts as "double magmatic belts". Stalling of the subduction of a buoyant ridge (van Wijk et al., 2001) rifts the upper plate to develop a passive continental margin, and then forms new oceanic crust above upwelling sub-ridge asthenosphere, separating the two magmatic belts, as has taken place in Baja California and the Gulf of California (Michaud et al., 2006). Such a plate boundary configuration can evolve further into an archipelagic architecture with continued oceanic spreading and subduction.

The western Altaids (Fig. 1a), one of the world's classic orogens, was generated by subduction of the western segment of the Paleo-Asian Ocean (Xiao et al., 2015). This orogen evolved along a major subduction zone with local archipelagic configurations, which generally formed via forearc and backarc spreading with one magmatic belt (Windley et al., 2007; Xiao et al., 2015). However, existing models cannot explain the 446-380 Ma double magmatic belt, between which developed 414-325 Ma oceanic crust developed in SW Junggar and Chinese North-Central Tianshan, an eastern extension of the Yili block (Fig. 1b). This complex configuration requires an alternative tectonomagmatic model.

This paper will present a new tectonic model for the evolution of SW Junggar and

North-Central Tianshan that includes mid-Paleozoic sub-parallel ridge-subduction leading to a Late Paleozoic archipelago configuration in the western Altaids.

## TECTONIC UNITS

Western Junggar is divisible into SW Junggar and NW Junggar units along a boundary north of the Tacheng basin-Mt. Xiemisitai-Hongguleleng (Fig. 1b). In north and west SW Junggar are 472-531 Ma OIB- and MORB-type ophiolites, and 379-414 Ma OIB- and MORB-type ophiolites depleted in Nb crop out in the Baijiantan area and along the Darbut Fault there are (Figs. 1b, 2a) (Zhang et al., 2011; Zhang et al., 2018). In the Mt. Xiemisitai-Mayile area in SW Junggar a 380-446 Ma SSZ-type gabbro-basalt-andesite-diorite-granite-rhyolite intrudes an Early Paleozoic accretionary complex (Chen et al., 2010; Yin et al., 2017). 300-349 Ma magmatism is widespread to north and south of the Late Paleozoic accretionary complex (Figs. 1b, 2a). NW Junggar includes Late Paleozoic Saur arc rocks, and an accretionary complex with Carboniferous turbidites juxtaposed with Ordovician Kujibai ophiolite (Figs. 1b, 2d)(Chen et al., 2017).

The Central Tianshan exposes Precambrian basement, a long-lived 300-476.5 Ma magmatic belt, and Silurian-Carboniferous mylonite, gneiss and amphibolites (Figs. 1b, 2e) (Wang et al., 2012). In the North Tianshan, situated between the Central Tianshan and SW Junggar, an accretionary complex consists of Carboniferous turbidites and 325-386 Ma OIB- and MORB-type ophiolites with depleted Nb (Figs. 1b, 2e) (Xu et al., 2006).

## METHODOLOGY

To exclusively constrain orogenic processes of a short-lived archipelagic architecture with dismembered accretionary complex and paired igneous arc is generally difficult, because many ways can evolve into this framework. In order to solve this issue, we firstly remove complicated younger orognic units and affiliate to an older episode at which just has one accretionary complex and a contemporaneous arc to constitute a subduction zone; then linking this subduction zone to evolving spatial relationships of following associated subduction episodes.

It is noteworthy that deduced results of each orogenic stage should match the facts and data collected from field work and indoor analysis.

## EARLY PALEOZOIC SUBDUCTION SYSTEM

Li et al. (2006) proposed that the North-Central Tianshan and SW Junggar in China (separated by the Aibihu Fault) evolved independently (Fig. 1b), but paleomagnetic data show that the SW Junggar underwent 35° counterclockwise post-Permian rotation (Fig. 1b)(Choulet et al., 2011) suggesting that it was previously aligned parallel with the North-Central Tianshan.

In SW Junggar a 479-446 Ma accretionary complex, containing 458-504 Ma blueschist and Ordovician-Silurian turbidites, lacks a coeval island arc. In the Central Tianshan a 476.5-439 Ma continental arc lacks a paired accretionary complex (Fig. 1b).

Moreover, SW Junggar and Central Tianshan were in contact by the Early-Middle Paleozoic, based on the following. (1) Quartzitic schist from Laba River at southern end of SW Junggar (Fig. 1b and DR2) and at Wenquan in the Central Tianshan (across the Aibihu Fault) share similar clastic components (Fig. 1b). (2) Silurian-Devonian

strata from SW Junggar have detrital zircon age peaks at 380-500, 600, 900-1000, 1500-1700, 2400-2500 Ma similar to those in the Central Tianshan (Figs. 1b, 2b, f, DR3a-b), and (3) contain Precambrian and 446-479 Ma clasts, the sources of which are absent in SW Junggar (Figs. 2a, b, e), indicating their provenance from the Central Tianshan. Accordingly, the evidence suggests that the SW Junggar accretionary complex and Central Tianshan arc constitute a 476.5-446 Ma trench-arc system (Fig. 3a).

## MIDDLE PALEOZOIC SUB-PARALLEL RIDGE-TRENCH INTERACTION

In the mid-Paleozoic continuous evolving subduction generated 380-446 Ma magmatic rocks that intruded the Early Paleozoic accretionary complex in SW Junggar (Chen et al., 2010) and a coeval magmatic arc in the Central Tianshan, forming a double-magmatic belt (Fig. 2). We interpret the magmatic rocks that intrude the accretionary complex (including adakitic granodiorites with positive $\varepsilon_{Nd}(t)$) in the Mt. Xiemisitai area (Fig. 3b) (Yin et al., 2017), as products of a slab window beneath SW Junggar, caused by (a) a subducted spreading ridge or (b) a slab tear in old subduction lithosphere (Calmus et al., 2011). Between the double magmatic belts, younger 325-414 Ma MORB-type ophiolites with depleted Nb occur in SW Junggar and Chinese North Tianshan, which may have developed in (c) a rift basin above a buoyant subducting slab or in (d) a back-arc/forearc basin.

If the MORB-type ophiolites developed in a sizable back-arc or forearc basin (model d), a coeval 349-380 Ma trench and island arc should be located in SW Junggar, in contrast to the actual field relationship (Fig. 1b).

The presence of 325-414 Ma ophiolites in the Late Paleozoic SW Junggar and

Chinese North Tianshan accretionary complexes makes the slab-tear model (b) unlikely, because they are younger than the time of the double magmatic belts (446-414 Ma).

Therefore, we prefer hypothesis (a, c) that a Middle Paleozoic ridge parallel to a trench subducted beneath SW Junggar (Fig. 3c), because it agrees best with the field relationships and has modern analogues. In our model, a buoyant subducted ridge stalled resulting in rifting of the upper plate and opening of a new SW Junggar/Chinese North Tianshan ocean, similar to the extant Gulf of California (Michaud et al., 2006). The trench migrated to the southern margin of this ocean in the Tianshan (Fig. 3c), enabling 414-386 Ma oceanic crust in SW Junggar to be accreted before the 386-325 Ma ophiolites in the Chinese North Tianshan (Figs. 1b, 2a, e). This resulted in the Central Tianshan continental arc being generated by a subduction system analogous to those in modern Alaska and Chile (Thorkelson et al., 2011) and 357-375 Ma deformation and metamorphism (Fig. 3c). The subduction of the spreading ridge may have resulted in magmatic interaction with an overlying metasomatized mantle wedge or it may have promoted partial melting of this mantle wedge to generate MORB-type oceanic crust with depleted Nb (Zhang et al., 2011); this would be similar to mafic rocks in the Gulf of California (Calmus et al., 2011).

Devonian shallow marine-terrestrial sediments with corals, brachiopods, sea lilies, and plants (Gong and Zong, 2015) were deposited on the northern margin of the Early Paleozoic accretionary complexes along the Mt. Xiemisitai-Barleik-Mayile line (Fig. 1b), and magmatism ceased from 380 to 349 Ma (Liu et al., 2017); these sedimentary-kinematic relations are similar to those in the young passive continental margin above

a remnant slab in Baja California (Paulssen and de Vos, 2017). Moreover, Carboniferous sandstones in SW Junggar contain 349-380 Ma detrital zircons suggesting a source in the Central Tianshan (Fig. 2a, c, e, 3c).

## ARCHIPELAGIC ARCHITECTURE OF THE WESTERN ALTAIDS

The new ocean evolved to form Late Paleozoic intra-oceanic subduction systems with a continental arc in an overall archipelago configuration. The ocean subducted southwards to generate the Chinese North Tianshan accretionary complex (Xu et al., 2006) and the long-lived Central Tianshan continental arc (Fig. 3d).

A double-vergent subduction system developed in SW Junggar (Zhang et al., 2011). Southward subduction generated an intra-oceanic arc at Guai 10 (Fig. 1b) in the NW Junggar Basin and an accretionary complex containing Carboniferous turbidites and the Baijiantan-Baikouquan ophiolites (Figs. 1b, 3d). Northward subduction resulted in formation of the Mt. Xiemisitai-Mayile-Barleik magmatic arc and an accretionary wedge including the Darbut ophiolite (Figs. 1b, 3d). The young ridge subducted (Fig. 3d) to generate the Baogutu adakites and high-Mg# sanukitoids and the Miaoergou charnockite (Zhang et al., 2011).

In NW Junggar, the Paleo-Asian Ocean subducted northward to form a Late Paleozoic accretionary complex that includes Carboniferous trench sandstones juxtaposed with the Ordovician Kujibai ophiolite (Fig. 3d) (Chen et al., 2017).

Our new model suggests that such an archipelagic architecture in the western Altaids evolved as a consequence of sub-parallel ridge subduction. This type of subduction mechanism and subsequent evolution leads to a complex rifting and

amalgamation. The recognition of double magmatic belts provides a means of tracking such a complex history in orogenic belts.

## IMPLICATIONS

Sub-parallel ridge-trench interactions characterize modern subduction zones, so such interactions would be expected in the formation of some ancient orogenic belts such as western Altaids. It is noteworthy that a spreading ridge can undergo multiple episodes of subduction, resulting in generation of an archipelagic framework.


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**FIGURE CAPTIONS**

Figure 1 (a) Geological map of the West Junggar and Chinese North-Central Tianshan,

showing spatial relationships of the main orogenic components, including 380-446 Ma double magmatic belts, separated by 325-414 Ma oceanic crust, intruded into an Early-Middle Paleozoic accretionary complex in SW Junggar and a magmatic arc in the Central Tianshan. See Figure DR1 for further details. (b) Inserted schematic map of East Asia showing the location of the Altaids (Xiao et al., 2015).

Figure 2 Time-stratigraphic relationships between ophiolites, magmatism, HP metamorphism, and detrital zircons in sedimentary rocks in SW Junggar (a-c), NW Junggar (d) and the Chinese North-Central Tianshan (e-f). Note the development of 380-446 Ma double magmatic belts, which are older than 325-414 Ma ophiolites in the SW Junggar and Chinese North Tianshan (a, e). Detrital zircons of Precambrian and 446-479, 349-380 Ma, which are magmatic gaps in the SW Junggar (a), are dated in Silurian-Devonian (b) and Carboniferous (c) strata. The source of these clasts is in the Central Tianshan (e-f). Light green bars and dark green graphs in b, c, f present detrital zircons of 300-550 and 550-3500 Ma, respectively.

Figure 3 Four diagrams illustrating the tectonic crustal evolution in the West Junggar and Chinese North-Central Tianshan, showing the progressive development of Early Paleozoic subduction zone, Middle Paleozoic sub-parallel ridge-trench interaction, and a final Late Paleozoic archipelagic framework by 349-316 Ma. Acronyms are defined in Fig. 1. Further discussion in the text.

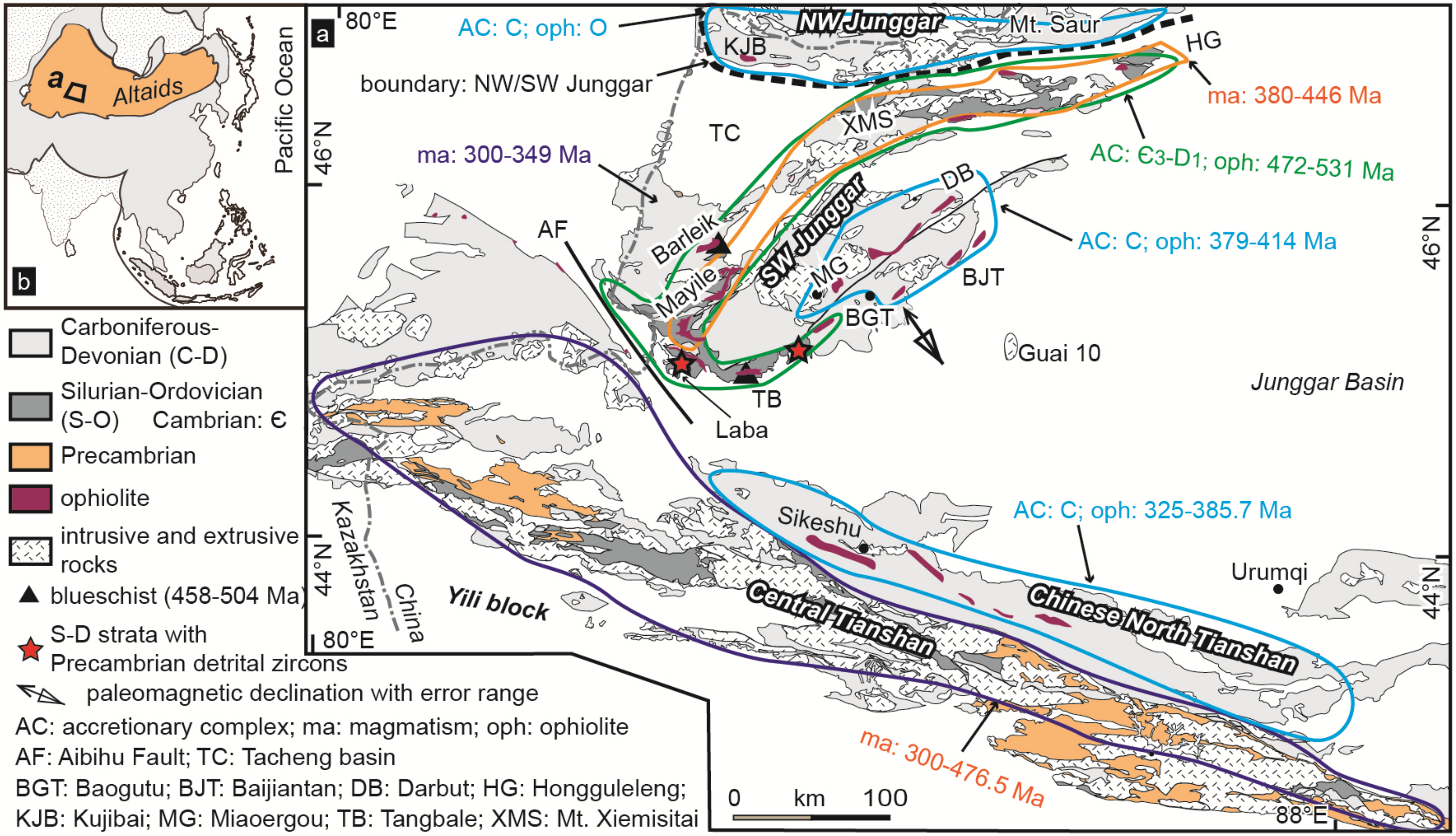


Figure 1 Zhang et al., 2019

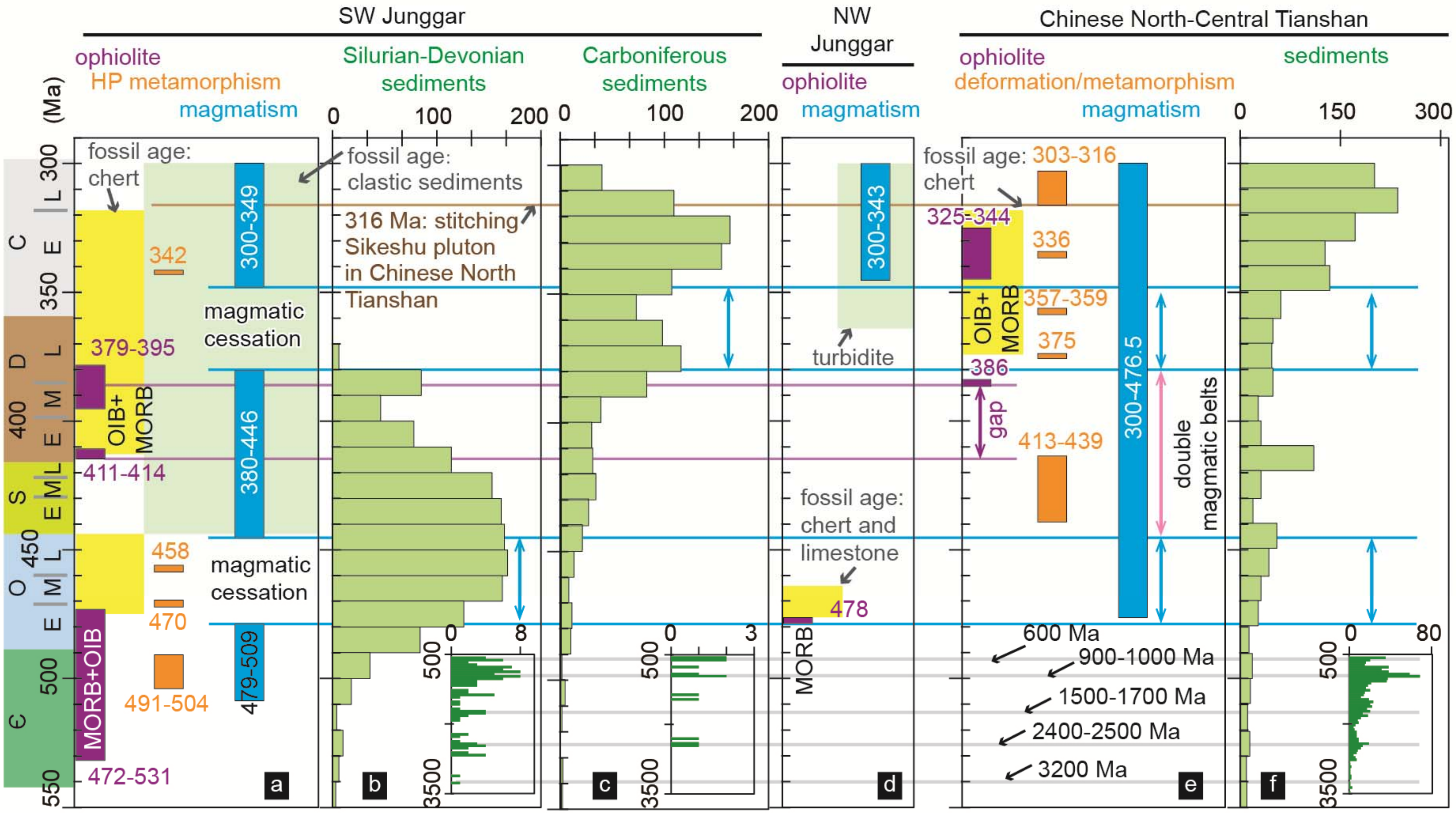


Figure 2 Zhang et al., 2019

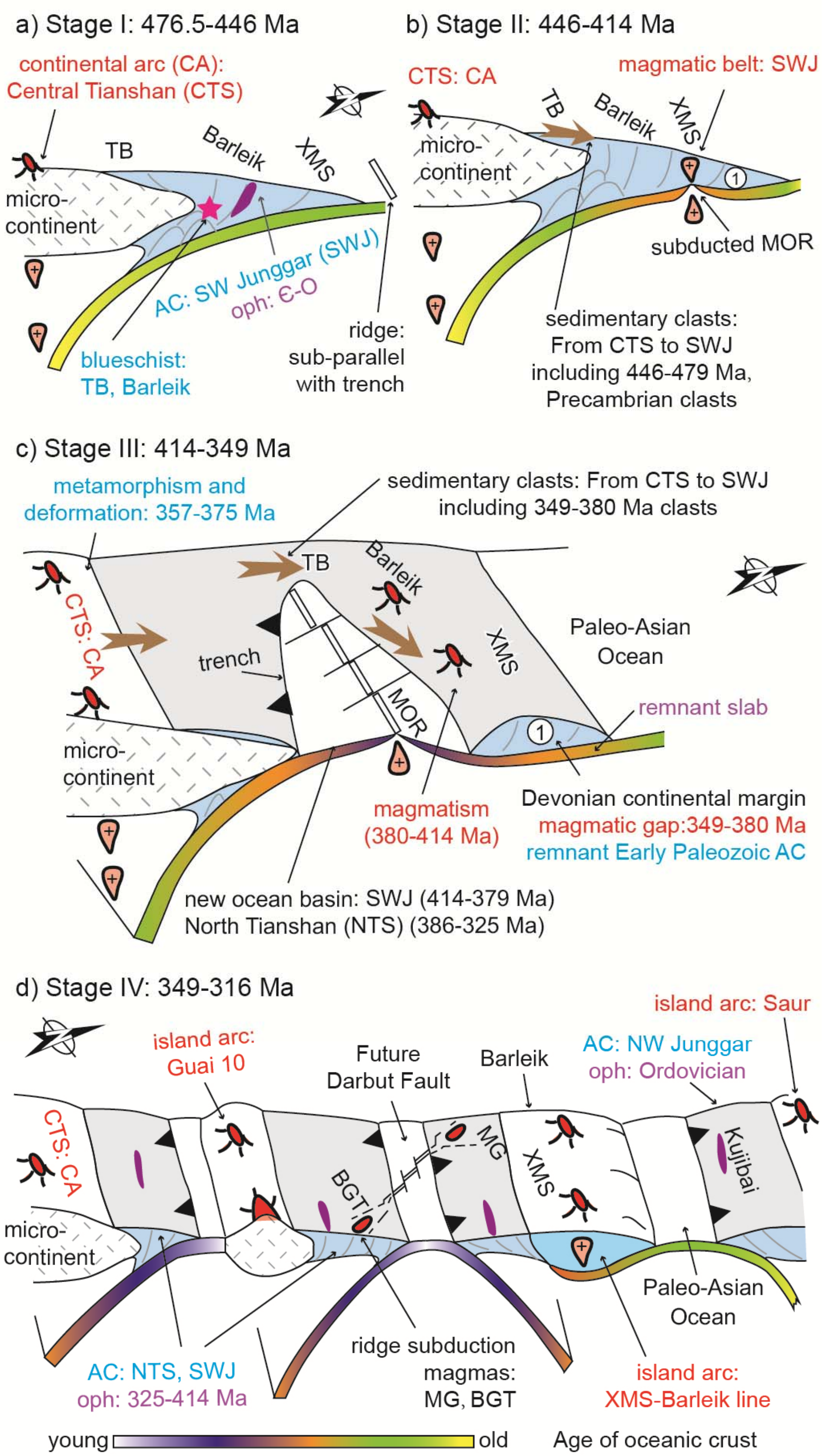


Figure 3 Zhang et al., 2019